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Periarticular Gunshot Fractures with the Formation of Primary Soft Tissue and Bone Structure Defects

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Introduction

Gunshot joint injuries (GJI) is one of the most complex nosologies in traumatology and reconstructive surgery of the limbs, combining a high risk of infectious complications, critical defects of soft tissues and bones, long-term loss of function and a high probability of disability. In modern conflicts, limb injuries make up the leading proportion of combat trauma; a significant contribution to the structure is made up of explosive lesions with multiple combined injuries, which require an integrated, interdisciplinary (orthoplastic) approach to treatment [1,2].

Ballistic injuries of the joint are formed both by direct destruction of the articular surfaces and subchondral bone, and by secondary hydrodynamic wave and cavitation, which causes "volumetric loss of soft tissues", segmental bone defects and wound contamination. Kinetic energy, density and elasticity of tissues, as well as the trajectory of the bullet, determine the scale of destruction and the unpredictable dissipation of energy in the joint [3].

Systematic reviews of 150 years of experience in the treatment of transarticular gunshot wounds show different complications profiles depending on the joint: the incidence of septic complications can reach 15% for the shoulder, 8% for the hip and about 2% for the knee joint; When combined with damage to hollow organs, the risk of infection for the hip joint increases even more. This determines the need for joint-specific algorithms

In addition to infections, the problems of joint instability, defects in the articular surfaces, post-traumatic osteoarthritis, neurological damage and chronic pain remain significant [4].

The evidence base for open fractures and combined defects clearly emphasizes early antibiotic prophylaxis (ideally within 1 hour from the moment of injury), adequate primary surgical treatment with the removal of non-viable tissues, stabilization and early closure of the soft tissue defect with the participation of microvascular techniques. The BOAST/BOA-BAPRAS guidelines and current reviews emphasize the feasibility of achieving a definitive soft tissue coverage within the first 72 hours after primary sanitation, which is associated with a reduction in infections and osteomyelitis [5-7].

In case of critical bone defects (traditionally >50% of the diameter of the cortical bone in the area of >1 cm), induced membrane (Maskele technique), multi-stage orthoplastic solutions with free flaps, combination with antibacterial cement spacers and subsequent bone restoration become relevant. Current reviews and clinical series confirm the viability of the MT for defects of long bones of various etiologies, including infected ones, subject to high-quality debridement, reliable stabilization and correct tactics of the second stage. At the same time, the most common problems remain the recurrence of infection and nonunion, especially with insufficient mechanical stability at the second stage [8,9].

For combat defects of the humerus, there is modern Ukrainian experience in the use of combinational strategies (stabilization, spacers, soft tissue plastics, bone reconstruction), which demonstrates the possibility of preserving the limb despite major defects [10].

The modern concept of "time-dependent management" of open fractures emphasizes the sequence of steps: antibiotics → revascularization (if necessary) → aggressive debridement → stabilization → dead space management/local antibiotic therapy → early soft tissue coating → delayed bone reconstruction (MT/bone autoplasty/combination techniques) [11].

Treatment of gunshot penetrating wounds of the joints requires specific requirements: joint sanitation, removal of foreign bodies (according to indications), restoration of stability, protection of cartilage and prevention of infection. The combined data of historical and modern examinations show that the risk of sepsis

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differs between joints, which leads to different management algorithms, in particular shoulder/hip/knee joints, etc. [12,13].

Despite the significant development of technology, a number of unresolved issues remain: the optimal time and volume of sanitation in case of high-energy gunshot wounds; criteria for choosing one-time versus staged recovery; the role of local antibiotic delivery systems to the joint and periarticular zones; predictors of IMT success (Induced membrane tachnice) in combination with flaps; integration of modern individualized implants and 3D planning into combat injury algorithms; biomarkers of osteomyelitis and post-traumatic osteoarthritis risk. Tools for assessing pain and quality of life after complex reconstructions, in particular in veterans with long-term pain syndromes, are also relevant [6,8].Conducting a systematic study aimed at the formation and validation of the algorithm for the management of gunshot wounds of joints with defects of soft tissues and bone structure, taking into account Ukrainian resource conditions (logistics, availability of microvascular care, staged reconstructions), has a high clinical and socio-economic significance. The expected result is a decrease in the frequency of infections, non-unions and amputations, a reduction in the duration of treatment and rehabilitation, an increase in the percentage of limb preservation and restoration of its function, and a reduction in long-term costs associated with disability.

- Purpose: The aim of the work was to analyze the results of treatment of patients with gunshot periarticular fractures with the formation of soft tissue and bone defects.
- Methods: An analysis of the treatment of 85 victims with this category of injuries was carried out, with an average age of 36.8 years (19-62), 81 men and 4 women.

STD has been divided into three types (Ferreira N, Tanwar YS. 2020): alpha - STD closes without reconstruction, beta - requires reconstruction, and gamma - soft tissue reconstruction is not possible.

Epimetaphyseal BD were divided into three groups: A - epiphyseal defect, B – metaphyseal defect and C - epimetaphyseal defect. Each group included three subtypes: I – BD up to 25%, II – 26-50% and III – 51% or more. The median follow-up was 12.8 (6-17) months. Surgical treatment of this group of patients included three stages.

During the first stage of treatment the debridement of the gunshot wound was carried out using a sufficient amount of saline, the reduction of bone fragments with the restoration of the limb axis, and the stable fixation of bone fragments using external fixation devices. During surgical treatment, all small non-fixed osteochondral fragments were removed with maximum preservation of the synovial membrane, through which important vessels pass for blood supply to the epimetaphyseal areas with revision of all parts of the articular surface, which is achieved by revising the wound in different positions in the joint: flexion-extension, adduction-abduction, internal-external rotation in order to maximize the view of the entire plane of the articular surfaces and volvulus for the object detection of damaged tissue or foreign bodies. During the second stage of treatment, the soft tissue defect was closed with the replacement of the bone defect with a spacer with the antibiotic gentamicin, vancomycin. Перевага цільного цементного спейсера над намистом полягає у формуванні безперервної індукованої мембрани, що актуально у методиці Masquelet. During the third stage of treatment, reconstructive surgeries on bone defects were performed.

Results and Discussion

In the structure of this category of wounded, the elbow joint prevailed - 24, knee - 23, ankle - 14, shoulder - 12, hip - 11 and wrist - 1. The median follow-up was 12.8 (6-17) months. The severity of injury and its complications determined the need for amputation at the 1st stage of treatment in 8 patients (with gamma type of STD and type B3 and C3 of BD and the MESS ≥7) – 9.4%. In all other patients the debridement and fixation of bone fragments with rod Ex-Fix was performed at the 1st stage. 2nd stage of treatment consisted of STD reconstruction in beta type of defects: a thoraco-dorsal flap, free flap and Italian technique was used in treatment of shoulder, elbow and wrist joints injuries, with the replacement of the bone defect of C3 type with a spacer (n=6), free movement of tissues –in 1 and the Italian technique – in 5 cases. For STD of the knee and ankle joints, the medial head of the calf muscle, free movement of tissues, sural flap and the Italian technique was used (Figure 1)

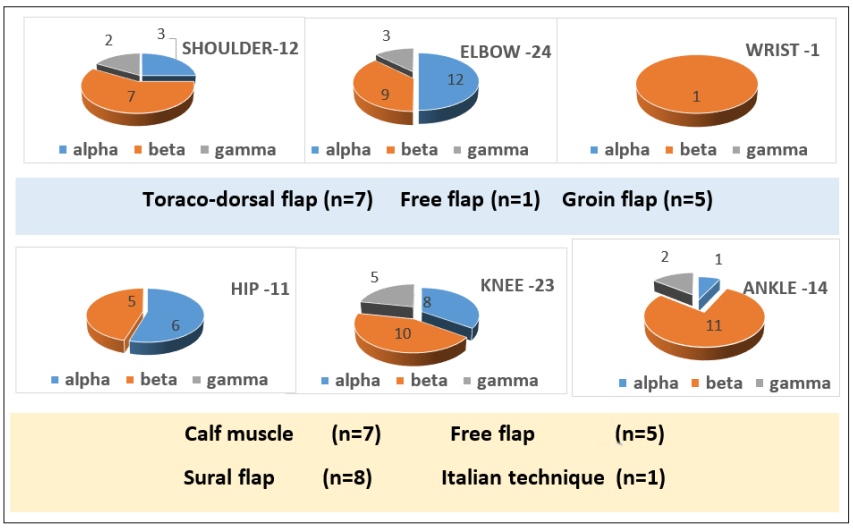

Figure 1: Distribution of Reconstructive Surgical Interventions for Soft Tissue Defects of Articular Localization

localization3d stage of treatment consisted of BD treatment with use of bone autoplasty, arthrodesis, endoprosthesis, Masquelet technique and scaffolds (Figure 2)

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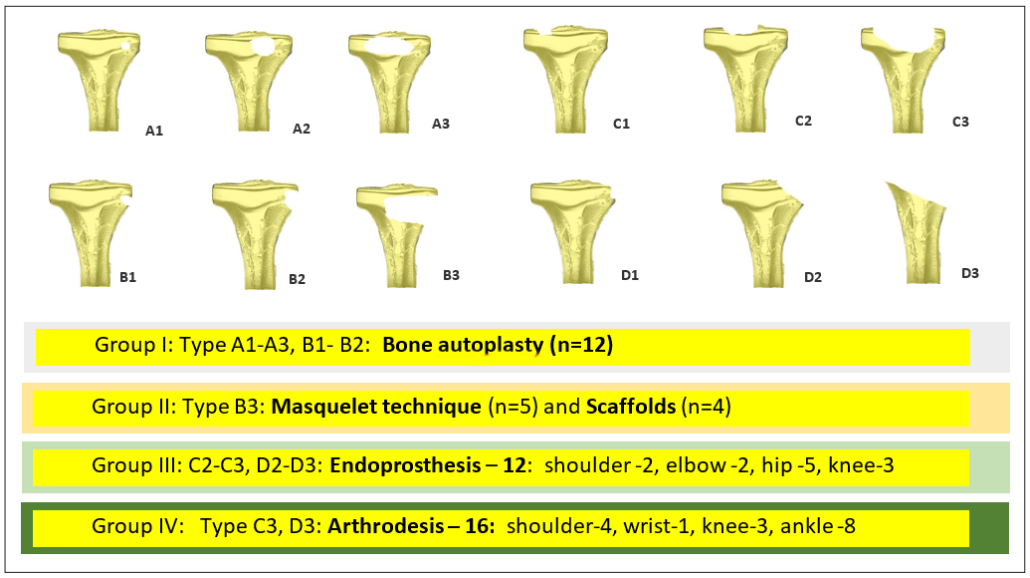
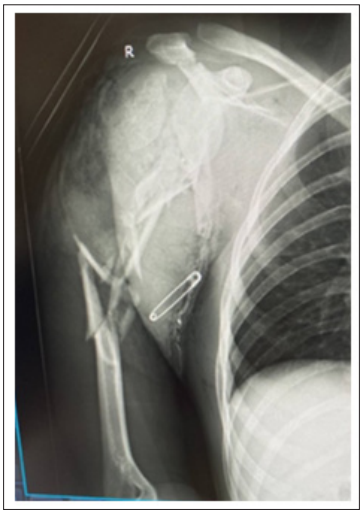


Figure 2: Distribution of Surgical Techniques Depending on the Type of Bone Defect

Autoplasty was performed for extra-articular localization defects alone or in combination with osteosynthesis using LCP and blocked nail. In case of defects in the articular surfaces of the C2-C3, D2-D3 type, arthroplasty of the joints was performed, namely: shoulder (2), elbow (2), hip (5) and knee (3) joints.

In case of defects in the articular surfaces of the shoulder joint up to 25%, the integrity of the rotator cuff of the shoulder and deltoid muscle, anatomical unipolar or total arthroplasty was performed. In case of damage to the rotator cuff of the shoulder, slight atrophy of the deltoid muscle, bone defects of the proximal epimetaphysis of the humerus and articular process of the scapula, reversible arthroplasty of the shoulder joint was performed. With a combination of the above factors and plexopathy with artrophy of the deltoid muscle, arthrodesis of the shoulder joint was performed. For extensive bone defects of the articular surfaces, additive technologies were used.



In the case of bone defects of the elbow joint, autoplasty with MOS reconstructive plates, arthroplasty and complex arthroplasty using additive technologies were performed. Arthrodesis of the elbow joint was not performed. Although it may be recommended for patients who need to do heavy work in the future.

In the case of a bone defect of the femoral head, primary prosthetics were performed. With a bone defect of the acetabulum, primary arthroplasty and complex arthroplasty were performed using additive technologies, when the size of the bone defect needed to be replaced by an augment.

For defects in the articular surfaces of the knee joint, unicondylar or total arthroplasty was performed. In difficult cases, with damage to the lateral collateral ligaments and extensive defects in the condyles of the thigh and tibia, LCCK or Hinge variants of knee endoprostheses were used in combination with additive technologies.

For defects in the articular surfaces of the knee and ankle joints with high risks of infectious complications, arthrodesis operations were performed to restore the resistance of the lower limb using screws, blocked rods or external fixation devices. In case of defects in the articular surfaces of the ankle joint, arthrodesis operations were performed in all cases. In case of chronic osteomyelitis of the articular surfaces, pronounced trophic changes in the skin and underlying soft tissues, amputation was performed above the level of the bone defect, followed by preparation of the patient for prosthetics. On clinical example No. 1, a dorachorsal flap and the replacement of a bone defect with a cement antibacterial spacer in b type soft tissue defect and bone defect type D3 are demonstrated, Figure 3.

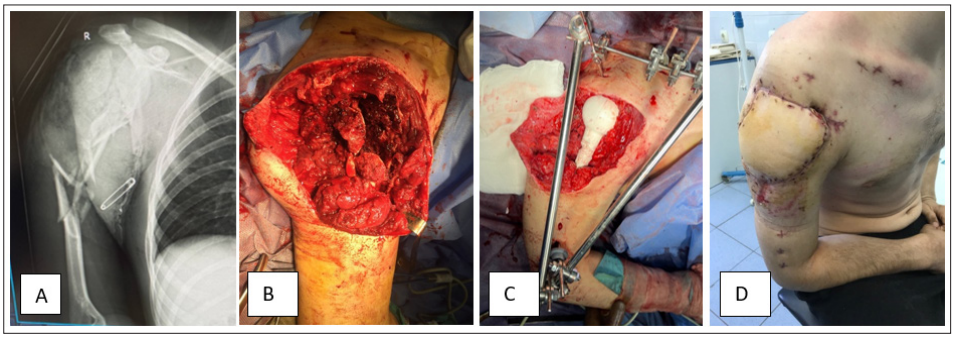


Figure 3: Gunshot shrapnel wound (20.04.2022) of the right shoulder with a gunshot multi-fragment fracture of the head and diaphysis of the right humerus along the proximal and middle third with a massive musculoskeletal defect. A - photoradiograph of the right shoulder joint, where a multi-fragmentary fracture of the proximal epimetadiaphysis of the humerus with the formation of a bone defect is noted. B - General view of the defect of the soft tissues of the right shoulder joint, where they are noted in the day wounds, fragments of the humerus. C – General view of the wound of the right shoulder joint, where the bone defect is replaced by a cement spacer. D – General view of the right shoulder joint after replacing the soft tissue defect with a doracodorsal flap.

Clinical example No. 2. Reversible arthroplasty of the shoulder joint in case of bone defect of the proximal epimetaphysis of the humerus D3, damage to the rotator cuff of the shoulder joint, as well as malnutrition of the deltoid muscle (Figure 4).

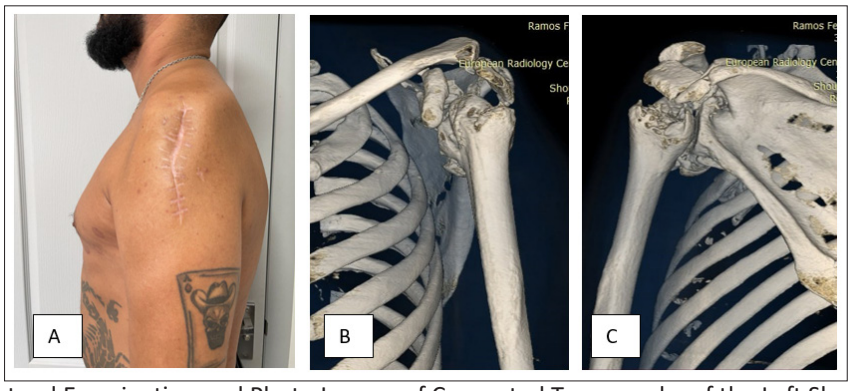


Figure 4: Lateral Examination and Photo Images of Computed Tomography of the Left Shoulder Joint.

A. Lateral examination of the left shoulder joint, where a strengthened postoperative scar and post-traumatic malnutrition of the posterior and lateral parts of the deltoid muscle as a result of a gunshot penetrating wound to the left shoulder joint are removed.

B. Anterior and C - posterior examinations of computed tomography of the left shoulder joint, where an incorrectly consolidated multifragmentary fracture with a bone defect of the head of the left humerus, anterior-superior part of the articular process of the scapula, beak-shaped and acromial processes of the scapula, total damage to the rotator cuff of the shoulder is noted.

This bone defect corresponds to D3 according to the classification, since the cortical-spongy defect of the epiphyseal-metaphyseal region is more than 40% with a defect in the articular surface is more than 50%. The soft tissue defect at the wound corresponds to the alpha type, therefore, its replacement at the previous stages was carried out with local tissues.

6 months after the injury, an operation was performed - reversible arthroplasty of the left shoulder joint (RSA) with an endoprosthesis Evolutis, UNIC, France with bone autoplasty of the defect of the anterior-superior articular process of the scapula with the beak-shaped process, Figure 5.

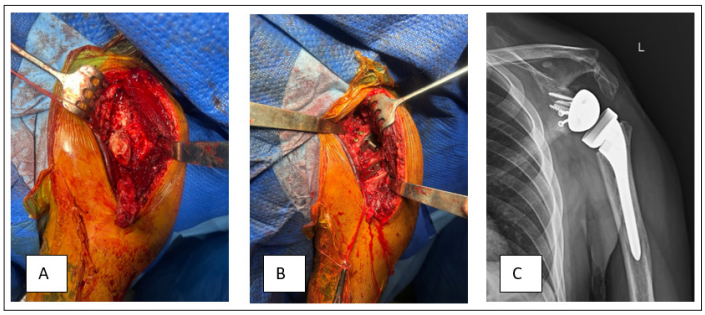


Figure 5: Stages of reversible arthroplasty of the left shoulder joint. A. - general view of the wound of the left shoulder joint, B - defect of the articular process of the scapula replaced by the beak-shaped process. B – photo of the anteroposterior projection of

the X-ray, where a reversible endoprosthesis of the left shoulder joint is noted.

During surgery, an incorrectly consolidating multi-fragment fracture of the head of the humerus with a bone defect was detected, which was replaced by scar tissue. The base of the beak-shaped process of the scapula without signs of consolidation. In addition, there was an incorrectly consolidated fracture of the acromial process of the scapula with a displacement of its main fragment downwards, which narrowed the subacromial space, a defect of the anterosuperior part of the articular process of the scapula. Taking into account the bone defect of the glenoid, it was plastic with a beak-shaped process with fixation with two spongy 3.5 mm screws. Taking into account the total damage to the rotator cuff of the shoulder joint, a reverse prosthesis of the shoulder joint was used. To achieve the stability of the endoprosthesis, lateralization of the shoulder component was performed using PE Humaral inlay +5 and the lower position of the Humeral cup. Given the narrowing of the subacromial space, a resection of the lower surface of the acromial process was performed.

The postoperative period proceeded without complications, rehabilitation was carried out according to the protocol after shoulder arthroplasty.

3 months after the operation, the active and passive range of motion in the left shoulder joint was assessed, which is shown in Figure 6

Figure 6: Photo of the volume of active movements in the left shoulder joint before (A and B) and after reversible arthroplasty (B and D) of the left shoulder joint. A - the absence of active abduction and B - active flexion in the left shoulder joint, C - active abduction is possible up to 45 degrees, D - active flexion in the left shoulder joint up to 50 degrees.

The achieved full range of motion in the left shoulder joint was not possible due to cicatricial changes and malnutrition of the deltoid muscle, as well as due to an incorrectly consolidated fracture of the acromial process of the scapula, which reduced the subacromial space.

Clinical example No. 3 Consequences of a gunshot wound (09/21/2023) of the left shoulder joint with the formation of a bone defect of the proximal epimetadiaphysis of the left humerus, total damage to the rotator cuff, severe malnutrition of the deltoid muscle of the left shoulder joint (Fig. 7).

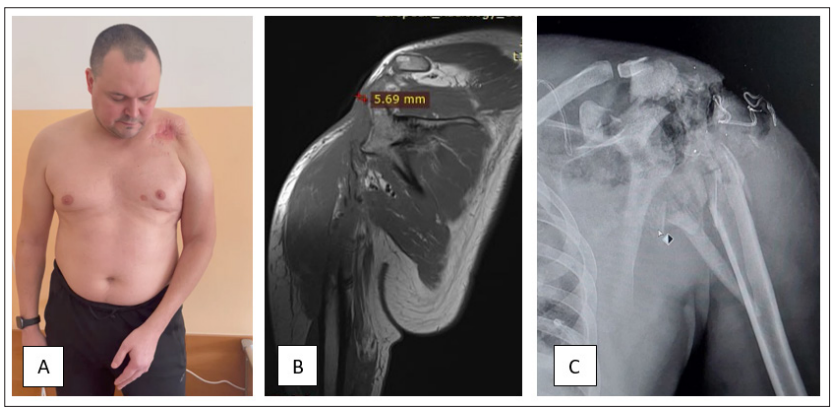


Figure 7: Consequences of a gunshot wound (21.09.2023) of the left shoulder joint. And the general view of the left shoulder joint, where there is a strengthened postoperative scar and pronounced malnutrition of the deltoid muscle. B – photo of the frontal section of the MRI of the left shoulder joint, where atrophy of the deltoid muscle is noted, the distance from the articular process of the scapula to the skin is 5.69 mm. B – photoradiograph of the left shoulder joint after injury, where a multi-fragment fracture of the proximal epimetadiaphysis of the left humerus with the formation of a bone defect is noted.

Before preoperative planning, the patient underwent arthrodesis of the left shoulder joint with an individual 3D print implant - a lattice (material: Ti-6A I4V) with plastic surgery of a bone defect with a cortico-spongy autograft from the wing of the left iliac bone and implant material "ActiveBone" (Figure 8).

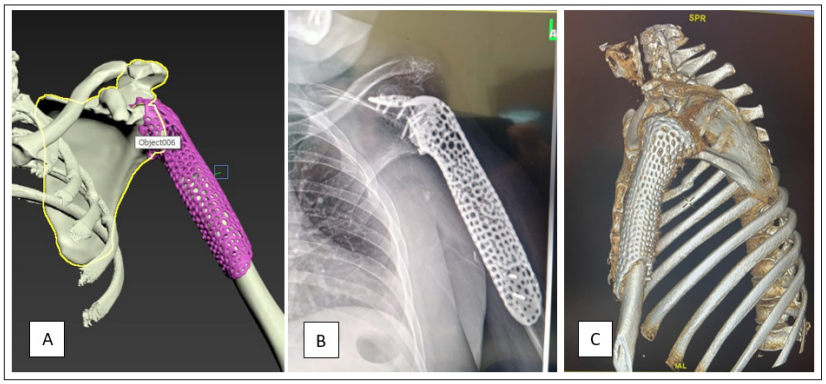


Figure 8: A - Preoperative 3D planning of the lattice to replace the bone defect of the left shoulder joint. B – Postoperative photoradiograph of the left shoulder joint after surgery: arthrodesis of the left shoulder joint with an individual 3D print lattice implant (material: Ti-6A-I4V). B – photo of a computed tomography of the left shoulder joint, where the replacement of the bone defect with a titanium lattice with arthrodesis of the left shoulder joint is noted.

The postoperative period proceeded without complications. The wound healed with the initial tension. In the postoperative period, the left shoulder joint was immobilized with an orthosis with a 30-degree abduction pillow and exercise therapy according to the rehabilitation protocol. 3 months after surgery, control computed tomography shows the formation of fusion in the area of arthrodesis with an active range of motion due to the scapula (Figure 9).

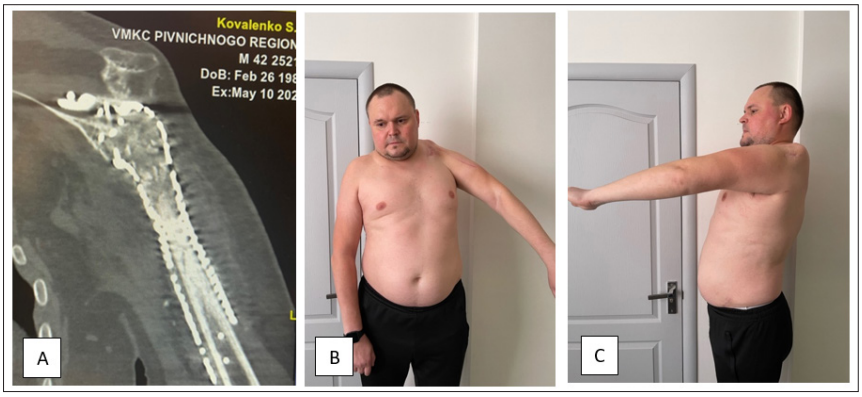


Figure 9: A - Frontal scan of computed tomography of the left shoulder joint, where the formation of arthrodesis is noted.

B - Active abduction in the scapulo-thoracic joint. C - Active flexion up to 80 degrees in the left scapulo-thoracic joint.

Clinical example No. 4, which demonstrates elbow arthroplasty using additive technologies in a patient with a multi-fragment unconsolidated intra-articular fracture of the distal epimetaphysis of the right humerus, proximal epimetaphysis of the right ulna with displacement and bone defect. Post-immobilization unstable combined contracture of the left elbow joint as a result of a gunshot shrapnel wound to the right elbow joint dated 01/25/2025. (Figure 10).

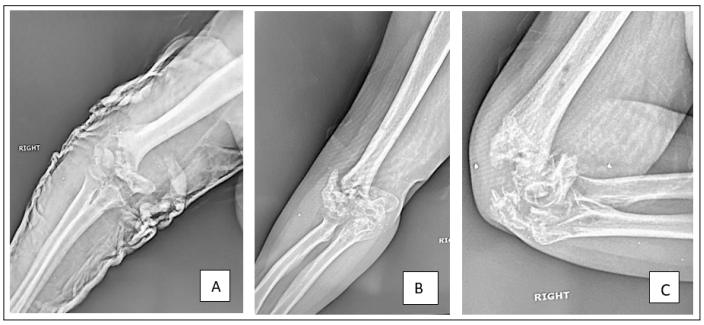


Figure 10: A – anterior photoradiograph of the right elbow joint after a gunshot shrapnel wound with a multi-fragment fracture of the distal epimetaphysis of the humerus, ulnar process of the ulna with displacement of fragments and a defect in the bone structure of type D III.

B - anterior and C - lateral photoradiographs of the right elbow joint 7 months after the injury.

Taking into account the lesions of the distal epimetaphysis of the right humerus and the inability to ensure the stability of the block of the shoulder component of the endoprosthesis due to a significant bone defect, the patient underwent preoperative planning and made 3D models, navigation resections, a trial augment for the distal part of the brachial cyst and, after approval, an individual titanium augment was made, which would ensure the correct positioning of the shoulder stem and the stability of the block of the shoulder component endoprosthesis (Figure 11).

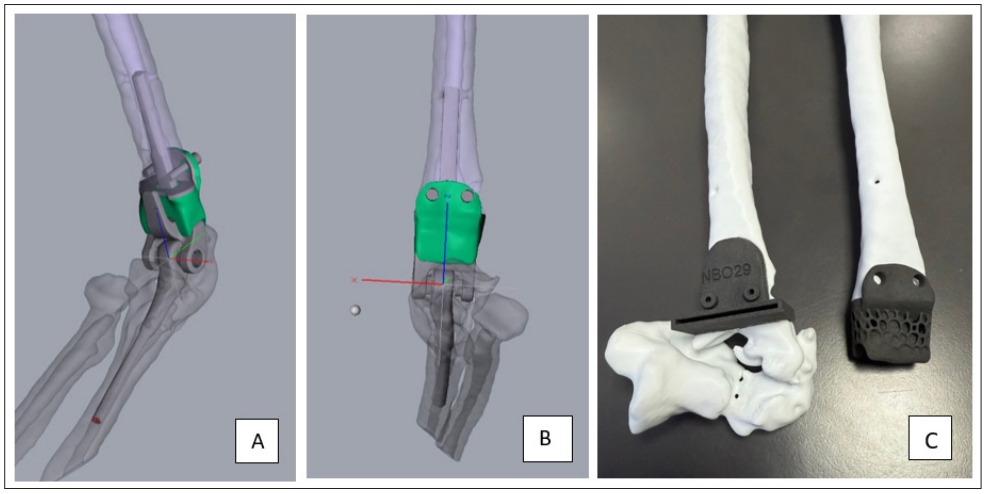


Figure 11: A and B - preoperative 3D planning of the endoprosthesis and shoulder augment, B - photo of the shoulder resector and trial shoulder augment for the block of the shoulder component of the elbow arthroplasty.

The use of a trial shoulder augment during surgery made it possible to accurately position the shoulder stem and permanent shoulder augment, which is important for maintaining axial relationships during movement in the shoulder arthroplasty. It should be noted that long cement legs were used to achieve better stability. In the position of the patient on the left side with a stand under the right upper limb from the posterior access, an operation was performed (08/22/25) - revision of the ulnar nerve, total cement arthroplasty of the right elbow joint with an Orthotech endoprosthesis using an individual shoulder 3D print implant with Ti6Al4V (Figure 12).

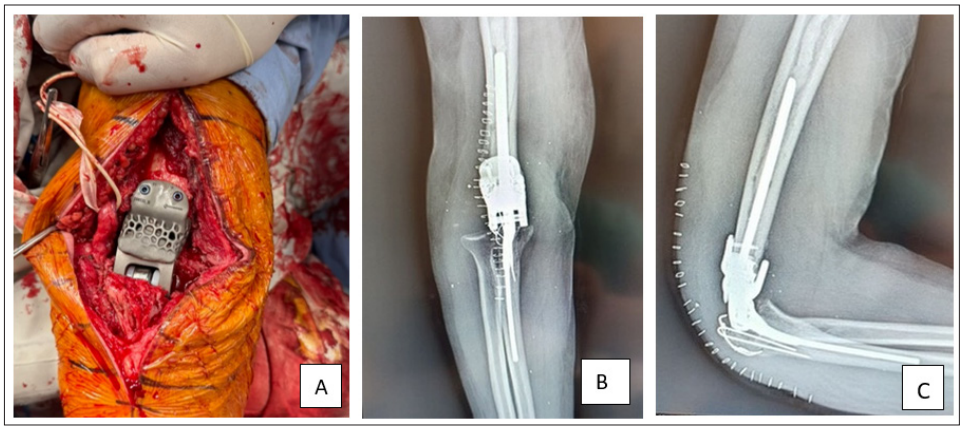


Figure 12: A – intraoperative photo of an individual shoulder 3D print implant with Ti6Al4V, the ulnar nerve is taken on a holder, B – anterior and C – lateral photoradiograph of the right elbow joint.

Clinical case No. 5. Gunshot tangential penetrating shrapnel wound (8.11.2022) of the right knee joint with a multi-fragment fracture of the kneecap with a defect in its structure, a defect in the kneecap ligament, a multi-fragment fracture with an osteocho-neural defect of the loading surface of the external condyle of the thigh, a defect in the tendon of the quadriceps femoris muscle and the medial kneecap holder (photo 10 A, B). 8.11.22 The patient underwent primary surgical treatment of the gunshot wound, fixation of fragments of the external condyle of the thigh using two Kirschner spokes of the right knee joint (photo 13 B, D).

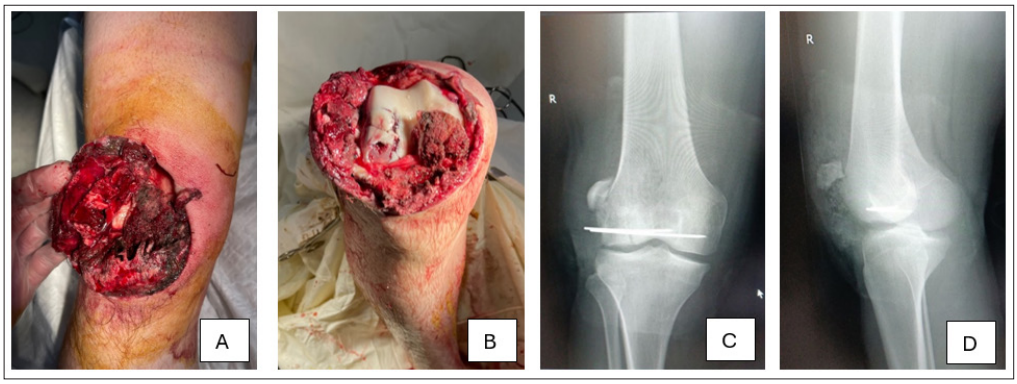


Figure 13: General view of the gunshot wound of the right knee joint (13 A, B) and photoradiograph in direct and lateral projections after fixation of fragments of the external condyle of the thigh with the help of two Kirschner spokes of the right knee joint (13 C, D).

Taking into account the defect of the anterior surface of the knee joint with damage to the extensor mechanism, the patient on 17.11.22. A staged operation was performed - combined plastic surgery of the soft tissue defect of the knee joint area with the medial head of the calf muscle and a split skin graft from the outer surface of the right thigh, Figure 14.

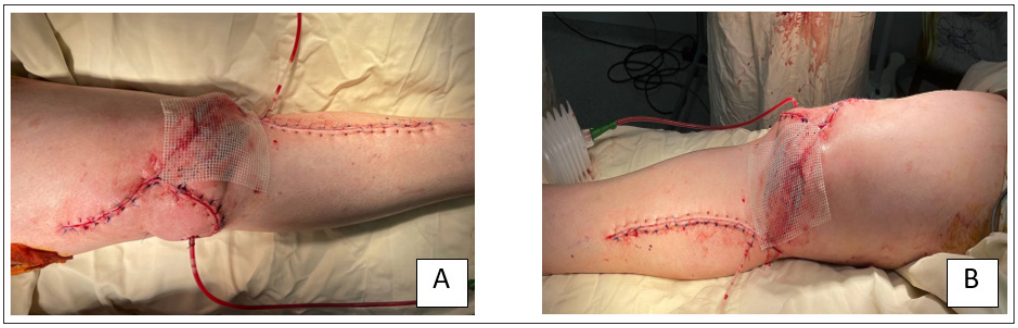


Figure 14: General view after plastic surgery of the soft tissue defect of the knee joint area with the medial head of the calf muscle and a split skin graft from the outer surface of the right thigh: A - anterior examination, B - medial examination.

Clinical outcome evaluated 9 months after injury, Fig 15.

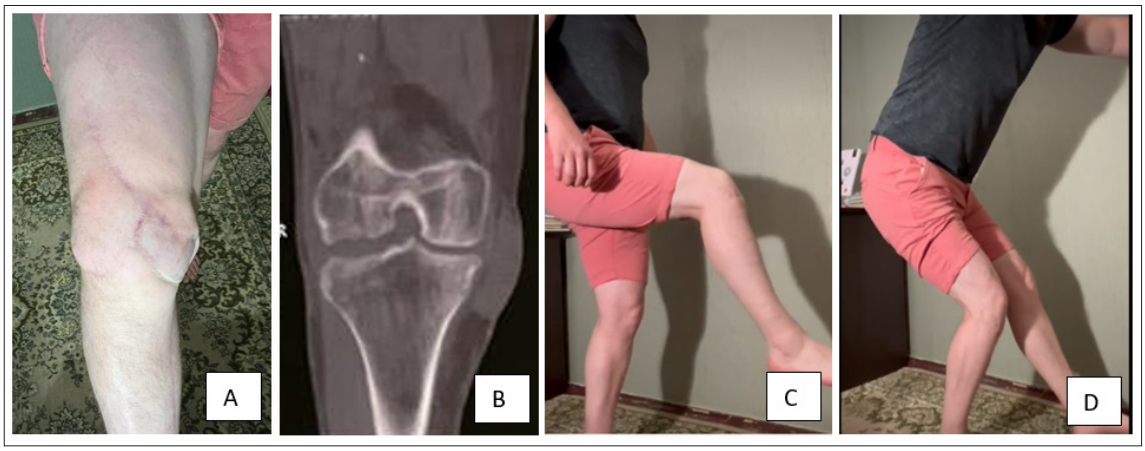


Figure 15:

A – General view of the right knee joint after injury and staged surgical interventions,

B – Photo of a frontal scan of CT, where post-traumatic arthrosis of the knee joint and a consolidated fracture of the external condyle are noted.

C and D - restriction of flexion in the right knee joint, but restoration of resistance of the right lower limb.

Conclusion

According to our research gunshot wounds to large joints in the structure of limb injuries, with the beginning of the full-scale Russian-Ukrainian war, increased from 16 to 23%. In the structure of joint injuries, a combination of soft tissue defects and bones of the epimetaphyseal area occurred in 14% of the victims.

Contractures in this category of patients occurred in 78.7%. Delayed union after autoplasty, osteosynthesis, the Masquelet technique and scaffolds in 88% of cases. Deep infection was 8.7%.

Treatment of the victims with gunshot combined defects of soft tissues and bone structure of periarticular localization is a difficult challenge today. Debridement, reduction and closure of soft tissue with planned reconstructive surgery allow a good treatment result. High percentage of joint contractures, infections and amputations of limbs persists, which leads to the search for other approaches to treatment.

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